

Attraction of a bark beetle predator, *Thanasimus undatulus* (Coleoptera: Cleridae), to pheromones of the spruce beetle and two secondary bark beetles (Coleoptera: Scolytidae)

THERESE M. POLAND¹ and JOHN H. BORDEN²

CENTRE FOR PEST MANAGEMENT, DEPT. OF BIOLOGICAL SCIENCES
SIMON FRASER UNIVERSITY, BURNABY, BC, V5A 1S6

ABSTRACT

The bark beetle predator *Thanasimus undatulus* Say was captured in statistically significant numbers (total catch = 470, 713, and 137) in three field experiments using multiple-funnel traps baited with various combinations of pheromones for the spruce beetle, *Dendroctonus rufipennis* Kirby, and the secondary bark beetles *Dryocoetes affaber* Mannerheim, and *Ips tridens* Mannerheim. *Thanasimus undatulus* was attracted to frontalin and α -pinene, the commercial spruce beetle lure, alone or combined with the *D. affaber* pheromones (+)-endo- and (+)-exo-brevicomin. *Ips tridens* pheromones, (+)- and (+)-ipsdienol, significantly increased the numbers of *T. undatulus* attracted to spruce beetle lures. Additional *I. tridens* pheromone components, (-)-cis-verbenol and amitinol, did not increase attraction to spruce beetle lures with added (+)-ipsdienol. Attraction to *I. tridens* pheromones indicates that baiting susceptible hosts with *I. tridens* pheromones to induce competitive exclusion of the spruce beetle may also lead to increased densities of the natural enemy, *T. undatulus*.

Key words: *Thanasimus undatulus*, *Dendroctonus rufipennis*, *Ips tridens*, *Dryocoetes affaber*, ipsdienol, kairomone, predator, Princeton, British Columbia

INTRODUCTION

There is an astonishing number of arthropod species associated with the subcortical galleries of bark beetles (Dahlsten 1982). Interactions among the co-existing organisms may greatly influence their dynamics and population distributions (Begon and Mortimer 1986). Mortality from arthropod predators and parasites may play an important role in keeping endemic bark beetle populations at low levels, thus minimizing the likelihood of large infestations (Whitmore 1983). Members of the family Cleridae are among the principal insect predators of several bark beetles (Dahlsten 1982).

The spruce beetle, *Dendroctonus rufipennis* Kirby, is the most destructive pest of mature spruce trees in Western North America (Safranyik 1988). Clerid predators may play only a small role in regulating spruce beetle populations. More significant causes of mortality include envelopment by resin, interspecific competition by other scolytids, and consumption by avian and dipteran predators (McCambridge and Knight 1972; Gara *et al.* 1995). *Ips tridens* Mannerheim and *Dryocoetes affaber* Mannerheim are the most common secondary bark beetles associated with the spruce beetle in Southern British

¹ Current Address: U.S.D.A. Forest Service, North Central Forest Experiment Station, 1407 S. Harrison Rd., Ste. 220, Michigan State University, East Lansing, MI 48823

² To whom all correspondence should be addressed

Columbia. To develop semiochemical-based management tactics for the spruce beetle using competitive displacement or exclusion by the secondary species, the role of semiochemicals in interspecific communication between the spruce beetle, *I. tridens*, and *D. affaber* was investigated.

Entomophagous insects, including numerous species of clerids, commonly use scolytid pheromones as kairomones in host recognition (Bakke and Kvamme 1981, Billings and Cameron 1984). *Thanasimus undatulus* Say is a generalist predator that is attracted to ipsdienol (Miller and Borden 1990), *cis*-verbenol plus ipsenol (Miller *et al.* 1991), and frontalin (Ross and Daterman 1995).

Thanasimus undatulus is a predator of the spruce beetle. It was attracted to traps baited with frontalin as a spruce beetle lure (Kline *et al.* 1974), and aggregated in large numbers on frontalin-baited spruce trees (Dyer 1973). Dyer and Hall (1980) found that addition of seudenol to frontalin did not significantly enhance attraction of *T. undatulus*. There is evidence that it can recognize the enantiomers of pheromones of its prey. *Thanasimus undatulus* was attracted preferentially to *S*-(-)-frontalin in a Douglas-fir stand, while both enantiomers were equally attractive in a spruce stand, a finding consistent with the observation that the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, preferred *S*-(-)- or (+)-frontalin over the *R*-(+)- enantiomer, while the spruce beetle appeared to be equally attracted to both *S*-(-)-, *R*-(+)-, and racemic frontalin (Lindgren 1992). Such specificity in response suggests that the importance of *T. undatulus* as a predator of spruce beetles may have been underestimated. For example, its larvae may not be very effective as subcortical predators of spruce beetle larvae (McCambridge and Knight 1972; Whitmore 1983), but adults may prey largely unnoticed on adult spruce beetles when they are colonizing new hosts, a hypothesis that is consistent with Dyer's (1973) observations.

To maximize the efficacy of pheromone-based management of bark beetle pests, negative effects on natural enemies must be minimized and positive effects encouraged. Accordingly, in the course of other experiments (Poland and Borden 1997) we collected and counted the *T. undatulus* adults attracted to pheromone-baited traps. Herein we report the responses of this predaceous clerid to combinations of pheromones for the spruce beetle, *I. tridens* and *D. affaber*.

MATERIALS AND METHODS

Field trapping experiments were conducted near Princeton, B.C. in mature stands composed of Engelmann spruce, *Picea engelmannii* Parry, lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, and subalpine fir, *Abies lasiocarpa* (Hook) Nutt. All experiments utilized twelve-unit multiple-funnel traps (Lindgren, 1983) set out in randomized complete blocks with at least 15 m between traps.

Semiochemical attractants for the spruce beetle, *I. tridens*, and *D. affaber* are summarized in Table 1. Various combinations of pheromone components for the three species were tested to determine their roles in interspecific communication. Numerous *T. undatulus* were captured in three experiments. Experiment 1, conducted from 29 June to 11 August 1994, compared numbers of spruce beetle and *D. affaber* attracted to combinations of spruce beetle lures and racemic mixtures of the two components of the *D. affaber* pheromone, *exo*- and *endo*-brevicomin. It comprised 20 replicates of five treatments: 1) unbaited control; 2) spruce beetle lure; 3) spruce beetle lure with (+)-*exo*-brevicomin; 4) spruce beetle lure with (+)-*endo*-brevicomin; and 5) spruce beetle lure with (+)-*exo*-brevicomin and (+)-*endo*-brevicomin. Experiment 2, conducted from 14

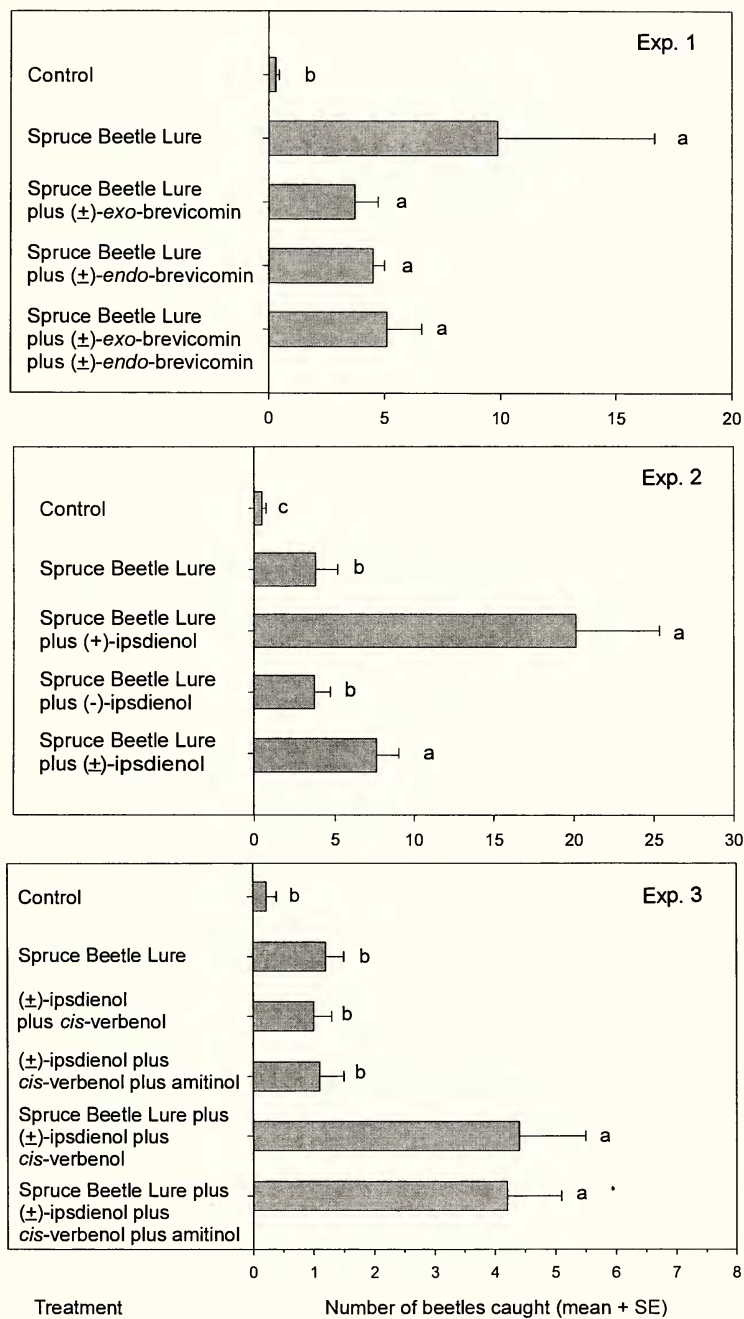


Figure 1. Mean number of *Thanosimus undatulus* captured in Experiments 1-3, 29 June - 17 Aug. and 14 July - 17 Aug. 1994, Arastra Creek, and 3 - 11 July 1996, Granite Creek, respectively, all near Princeton, BC. Spruce beetle lures consisted of frontalin released at 2.6 mg per 24 h and α -pinene released at 1.5 mg per 24 h. (±)-exo- and (±)-endo-Brevicomin (Exp. 1) were released at 0.2 mg per 24 h. Enantiomers of ipsdienol (Exp. 2) were released at 0.2 mg per 24 h. In Experiment 3, ipsdienol, (-)-cis-verbenol, and amitinol were released from bubble caps at 0.2, 0.6, and 0.2 mg per 24 h, respectively. N=20, 20 and 10 for Experiments 1 - 3 respectively. For each experiment, bars with the same letter are not significantly different, REGW test, $p < 0.05$.

July to 17 August 1994, compared numbers of spruce beetle and *I. tridens* attracted to combinations of spruce beetle lures and the different enantiomers of ipsdienol, a component of the *I. tridens* pheromone. It comprised 20 replicates of five treatments: 1) unbaited control; 2) spruce beetle lure; 3) spruce beetle lure with (+)-ipsdienol; 4) spruce beetle lure with (-)-ipsdienol; and 5) spruce beetle lure with (±)-ipsdienol. Experiment 3, conducted from 3 to 11 July 1996, compared numbers of spruce beetle and *I. tridens* attracted to spruce beetle lures and three components of *I. tridens* pheromone, (+)-ipsdienol, (-)-*cis*-verbenol, and amitinol. It comprised 10 replicates of six treatments: 1) unbaited control; 2) spruce beetle lure; 3) (±)-ipsdienol and (-)-*cis*-verbenol; 4) (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol; 5) spruce beetle lure with (±)-ipsdienol and (-)-*cis*-verbenol; and 5) spruce beetle lure with (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol.

Spruce beetle lures consisted of α -pinene released at 1.5 mg per 24 h from 1.5 mL Eppendorf tubes and frontalin released at 2.6 mg per 24 h from 400 μ L Eppendorf tubes (Phero Tech Inc.). Racemic *exo*- and *endo*-brevicomin (98.0% and 95.6% chemical purity, respectively, Phero Tech Inc.) were released at 0.2 mg per 24 h from glass capillary tubes (1.0 mm ID) sealed at one end and placed in perforated Eppendorf tubes (Stock *et al.* 1990). Racemic and chirally pure (97%) ipsdienol were released at 0.2 mg per 24 h from bubble caps (Phero Tech Inc.). *cis*-Verbenol was released at 0.6 mg per 24 h from bubble caps (Phero Tech Inc.). Amitinol (*trans*-2-methyl-6-methylene-3,7-octadien-2-ol) was prepared by the method of Francke *et al.* (1980) from (±) ipsdienol (BRI, Danbury, Connecticut) and purified to 98% by flash chromatography on silica gel using pentane-ether (2:1, v/v) as eluent (H.D. Pierce, Jr., Dept. of Chemistry, S.F.U.). Amitinol was released from bubble caps at 0.02 mg per 24 h (Phero Tech, Inc.).

Captured *T. undatulus* were collected and stored in plastic bags at -18 °C until counted. The numbers captured were transformed by $\log(x + 1)$ to satisfy assumptions of normality and homoscedasticity (Zar 1984) and then subjected to ANOVA for randomized complete block design treating replicates as blocks. The means were compared by the Ryan-Einot-Gabriel-Welsch (REGW) multiple *F*-test (SAS 1990).

RESULTS AND DISCUSSION

In Experiment 1, *T. undatulus* was attracted to spruce beetle lures alone and combined with (±)-*exo*-, (±)-*endo*-, or both (±)-*exo*- and (±)-*endo*-brevicomin (Figure 1). The brevicomins did not alter the number of *T. undatulus* attracted to the spruce beetle lure significantly. This indicates that *T. undatulus* either does not respond to (±)-*exo*- or (±)-*endo*-brevicomin or that responses to the brevicomins alone (not tested) are not enhanced by the presence of frontalin. Since clerids apparently exhibit preferences for enantiospecific pheromones (Lindgren 1992, Herms *et al.* 1991), a lack of response to (±)-*exo*- or (±)-*endo*-brevicomin by *T. undatulus* would not rule out kairomonal recognition of *D. affaber* as prey. For example, *T. undatulus* may require the enantiospecific pheromone of *D. affaber* consisting of a 1:2 ratio of the (+) enantiomers of *exo*- and *endo*-brevicomin (Camacho *et al.* 1994) to elicit a response. However, *T. undatulus* was not captured in sufficient numbers in experiments that tested spruce beetle and *D. affaber* responses to enantiospecific pheromone components for *D. affaber* to allow for statistical data analysis.

Spruce beetle lures also attracted *T. undatulus* in Experiment 2. (±)-Ipsdienol and particularly (+)-ipsdienol significantly enhanced the number of *T. undatulus* attracted to spruce beetle lures (Figure 1). Herms *et al.* (1991) found that the related species, *T. dubius* (F.), was attracted to different blends of (+)- and (-)-ipsdienol but preference

differed at different sites in Wisconsin and Michigan and in different years. Both frontalin and ipsdienol are known to attract *T. undatulus*. The results of Experiment 2 show that *T. undatulus* can recognize and respond to the (+) enantiomer of ipsdienol and that there is a synergistic effect of combining the two host kairomones. Because we have found that *I. tridens* produces mainly (-)-ipsdienol, *T. undatulus* may be better adapted to respond to pine engravers, *I. pini* (Say), that produce predominantly (+)-ipsdienol in B.C. (Miller *et al.* 1996). Alternatively, because *I. tridens* does produce small amounts of (+)-ipsdienol, *T. undatulus* may exploit a minor semiochemical product of *I. tridens* for prey location.

Table 1
Summary of semiochemicals and their biological activities for *Dendroctonus rufipennis*, *Ips tridens*, and *Dryocoetes affabe*.

Species	Semiochemical	Biological Activity	Reference
<i>D. rufipennis</i>	α -pinene	attractive	(Furniss <i>et al.</i> 1976)
	frontalin	attractive	(Gries <i>et al.</i> 1988)
<i>D. affaber</i>	(+)- <i>exo</i> -brevicomín (+)- <i>endo</i> -brevicomín	optimal attraction to 1:2 ratio of (+) enantiomers of <i>exo</i> - and <i>endo</i> -brevicomín	(Camacho <i>et al.</i> 1994)
	(-)- <i>exo</i> -brevicomín (-)- <i>endo</i> -brevicomín	no activity inhibits response to optimal blend	
<i>I. tridens</i>	(\pm)-ipsdienol	attractive	(Moeck <i>et al.</i> 1985)
	(-)- <i>cis</i> -verbenol	attractive	(Poland 1997)
	amitinol	attractive	

The results of Experiment 3 showed that traps baited with combinations of spruce beetle lures and (\pm)-ipsdienol and (-)-*cis*-verbenol or (\pm)-ipsdienol, (-)-*cis*-verbenol, and amitinol, caught significantly more *T. undatulus* than traps baited with spruce beetle lures alone, *I. tridens* pheromones alone, or the unbaited control traps (Figure 1). Although the addition of *cis*-verbenol or amitinol did not increase catches of *T. undatulus*, they did not decrease them significantly. *Thanasimus undatulus* may respond to key pheromone components that are commonly produced by many species, regardless of the presence of additional components that may be part of the pheromone blend of particular species.

The total numbers of *T. undatulus* captured across treatments were 470, 713, and 137 in Experiments 1-3 respectively. The corresponding numbers of scolytids captured were 435 spruce beetles, 2 *I. tridens*, and 2917 *D. affaber* in Experiment 1, 301 spruce beetles, 11 *I. tridens*, and no *D. affaber* in Experiment 2, and 73 spruce beetles, 1363 *I. tridens*, and 2 *D. affaber* in Experiment 3. *Thanasimus undatulus* outnumbered spruce beetles captured in all experiments and there were approximately 6 *D. affaber* captured for each *T. undatulus* in Experiment 1 and 10 *I. tridens* per *T. undatulus* in Experiment 3. These

results suggest that *T. undatulus* is attracted to pheromone components of its prey in numbers that may have an impact on scolytid populations.

Attraction of *T. undatulus* to *I. tridens* pheromones indicates that baiting susceptible host trees with *I. tridens* pheromones to induce competitive exclusion of the spruce beetle may also increase the density of the natural enemy, *T. undatulus*. If *T. undatulus* were to prey preferentially on the spruce beetle, the reduction of spruce beetle populations due to competitive displacement or exclusion by *I. tridens* (Poland 1997) would be augmented. On the other hand, the preferences of *T. undatulus* for small scolytids like *I. tridens* (Kline and Rudinsky 1964; Schmitz 1978) may partially offset the effects of competition on the spruce beetle. Non-preference by *T. undatulus* may simply reduce the level of interspecific competition by reducing population densities of both scolytid species.

ACKNOWLEDGEMENTS

We thank L.J. Chong, P. Kohen, R.D. Poland, R.R. Setter, and D. Thiessen for assistance, and L. Safranyik, G. Gries, and B.S. Lindgren for helpful suggestions on the manuscript. The research was supported by the Natural Sciences and Engineering Council of Canada, The Canadian Forest Service, the B.C. Ministry of Forests, the Science Council of B.C., The Coast Forest and Lumber Association, the Interior Lumber Manufacturers' Association, the Cariboo Lumber Manufacturers' Association, Phero Tech Inc., Canadian Forest Products Ltd., International Forest Products Ltd., Finlay Forest Products Ltd., Northwood Pulp and Timber Ltd., Timber West Ltd., Tolko Industries Ltd., Western Forest Products Ltd., and Weyerhaeuser Canada Ltd.

REFERENCES

- Bakke, A. and Kvamme, T. 1981. Kairomonal response in *Thanasimus* predators to pheromone components of *Ips typographus*. *Journal of Chemical Ecology* 7: 305-312.
- Begon, M. and Mortimer, M. 1986. *Population ecology: a unified study of animals and plants*. Second Edition, Blackwell Scientific Publications, Palo Alto, California.
- Billings, R.F., and Cameron, R.S. 1984. Kairomonal responses of Coleoptera: *Monochamus titillator* (Cerambycidae), *Thanasimus dubius* (Cleridae), and *Temnochila virescens* (Trogositidae), to behavioral chemicals of southern pine bark beetles (Coleoptera: Scolytidae). *Environmental Entomology* 13: 1542-1548.
- Camacho, A.D., Pierce, H.D. Jr., and Borden, J.H. 1994. Aggregation pheromones in *Dryocoetes affaber* (Mann.) (Coleoptera: Scolytidae): stereoisomerism and species specificity. *Journal of Chemical Ecology* 20: 111-124.
- Dahlsten, D.L. 1982. Relationships between bark beetles and their natural enemies. pp. 140-182. in: Mitton, J.B. and Sturgeon, K.B. (eds.) *Bark beetles in North American conifers: a system for the study of evolutionary biology*. University of Texas Press, Austin, TX.
- Dyer, E.D.A., and Hall, P.M. Effect of the living host tree (*Picea*) on the response of *Dendroctonus rufipennis* (Coleoptera: Scolytidae) and a predator *Thanasimus undatulus* (Coleoptera: Cleridae) to frontalin and seudenol. *The Canadian Entomologist* 112:167-171.
- Dyer, E.D.A. 1973. Spruce beetle aggregated by the synthetic pheromone frontalin. *Canadian Journal of Forest Research* 3: 486-494.
- Francke, W., Sauerwein, P., Vité, J.P., and Klimetzek, D. 1980. The pheromone bouquet of *Ips amitinus*. *Naturwissenschaften*. 67: 147-148.
- Furniss, M.M., Baker, B.H., and Hostetler, B.B. 1976. Aggregation of spruce beetles (Coleoptera: Scolytidae) to seudenol and repression of attraction by methylcyclohexenone in Alaska. *The Canadian Entomologist* 108: 1297-1302.
- Gara, R.I., Werner, R.A., Whitmore, M.C., and Holsten, E.H. 1995. Arthropod associates of the spruce beetle, *Dendroctonus rufipennis* (Kirby) (Col., Scolytidae) in spruce stands of south-central and interior Alaska. *Journal of Applied Entomology* 119: 585-590.

- Gries, G., Pierce, H.D., Jr., Lindgren, B.S., and Borden, J.H. 1988. New techniques for capturing and analyzing semiochemicals for scolytid beetles (Coleoptera: Scolytidae). *Journal of Economic Entomology* 81: 1715-1720.
- Herns, D.A., Haack, R.A., and Ayers, B.D. 1991. Variation in semiochemical-mediated prey predator interactions: *Ips pini* (Scolytidae) and *Thanasimus dubius* (Cleridae). *Journal of Chemical Ecology* 17: 515-524.
- Kline, L.H. and Rudinsky, J.A. 1964. Predators and parasites of the Douglas-fir beetle: Description and identification of the immature stages. Agri. Expt. Sta., Oregon State University. Tech. Bull. 79.
- Kline, L.H., Schmitz, R.F., Rudinsky, J.A., and Furniss, M.M. 1974. Repression of spruce beetle (Coleoptera) attraction by methylcyclohexenone in Idaho. *The Canadian Entomologist* 106: 485-491.
- Lindgren, B.S. 1983. A multiple funnel trap for scolytid bark beetles. *The Canadian Entomologist* 115: 299-302.
- Lindgren, B.S. 1992. Attraction of Douglas-fir beetle, spruce beetle and a bark beetle predator (Coleoptera: Scolytidae and Cleridae) to enantiomers of frontalin. *Journal of the Entomological Society of British Columbia* 89:13-17.
- McCambridge W. F. , and Knight, F.B. 1972. Factors affecting spruce beetles during a small outbreak. *Ecology* 53:830-839.
- Miller, D.R., Borden, J.H., and Slessor, K.N. 1996. Enantiospecific pheromone production and response profiles for populations of pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae), in British Columbia. *Journal of Chemical Ecology* 22: 2157-2172.
- Miller, D.R., Borden, J.H., King, G.G.S., and Slessor, K.N. 1991. Ipsenol: an aggregation pheromone for *Ips latidens* (LeConte) (Coleoptera: Scolytidae). *Journal of Chemical Ecology* 17:1517-1528.
- Miller, D.R. and Borden, J.H. 1990. β -Phellandrene: kairomone for pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae). *Journal of Chemical Ecology* 16:2519-2532.
- Moeck, H.A., Safranyik, L., Simmons C.S., and Lawko, C.M. 1985. *Ips tridens* (Coleoptera: Scolytidae) attracted by ipsdienol plus *cis*-verbenol. *The Canadian Entomologist* 117: 955-960.
- Poland, T.M. 1997. Competitive interactions between the spruce beetle, *Dendroctonus rufipennis* Kirby, and two secondary species, *Ips tridens* Mannerheim and *Dryocoetes affaber* Mannerheim (Coleoptera: Scolytidae). Ph.D. dissertation. Simon Fraser University, Burnaby, BC.
- Poland, T.M., and Borden, J.H. 1997. Disruption of secondary attraction of the spruce beetle, *Dendroctonus rufipennis* Kirby, by pheromones of two sympatric species (Coleoptera: Scolytidae). *Journal of Chemical Ecology* in press.
- Ross, D.W., and Daterman, G.E. 1995. Efficacy of an antiaggregation pheromone for reducing Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (Coleoptera: Scolytidae), infestation in high risk stands. *The Canadian Entomologist* 127:805-811.
- Safranyik, L. 1988. The population biology of the spruce beetle in western Canada and implications for management. pp. 3-23, in: Payne, T.S., and H. Saarenmaa (eds.) *Integrated Control of Scolytid Bark Beetles*. VPI and State University. Blacksburg, VA.
- SAS Institute. 1990. SAS System for personal computers, release 6.04. SAS Institute Inc., Cary. North Carolina.
- Schmitz, R.F. 1978. Taxonomy and bionomics of the North American species of *Thanasimus* Latreille (Coleoptera: Cleridae). Ph.D. dissertation. University of Idaho. Moscow, ID.
- Whitmore, M.C. 1983. The interaction of bark beetle (Coleoptera: Scolytidae) populations with their arthropod predators and parasites in felled Alaskan white spruce. M.Sc. thesis. University of Washington, Seattle, WA.
- Zar, J.H. 1984. *Biostatistical analysis*. Second edition. Prentice Hall, Engelwood Cliffs.

